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Maar Stories: How Oral Traditions Aid Understanding of Maar Volcanism and Associated Phenomena during Preliterate Times

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Ancient stories recalling catastrophic events were developed, sometimes encoded in myth, and passed down across several millennia in largely oral contexts. Volcanism is well suited to such stories and there are examples of extant stories recalling eruptions that occurred several millennia ago. This study focuses on a subset of these stories—those that recall the formation and subsequent (hazard-related) manifestations of maar volcanoes. Because these form as a result of the mixing of magma and groundwater, which produces explosive phreatomagmatic eruptions, they are among the most memorable catastrophic volcanic phenomena. Ancient stories recalling maar formation are known from Australia where cultural isolation for most of the past 65,000 years explains the extraordinary longevity and replication fidelity of such stories. Stories referring to the postformation developments of maars from Lake Albano in Italy are also described, together with less readily interpreted stories from elsewhere. Motif analysis suggests that preliterate peoples incorporated their observations of maar formation into stories as the shrieks of birds (escaping gas) and the approach of demons (eruptions), as well as narrative details such as the sky turning red and the ground surface twisting and cracking. Motifs referring to posteruption activity at maars include those that recall craters filling with water and ones that recall associated breaches of crater rims, lahars, and flooding downslope. The existence of maar stories of the kinds described and their demonstrable potential for adding detail and explanation to particular events several millennia ago should encourage geographers to treat such information sources with more respect than has been customary. *Key Words: lahar, local knowledge, maar, maar lake, oral traditions, volcanism.*

回忆灾难事件的古老传说, 是在神话中进行建构、且偶尔转译为神话, 并多半在口述的脉络中传承数千年。火山作用正好座落在此般故事中, 并且有现存的故事案例回忆数千年前发生的火山喷发。本研究聚焦这些故事的一个分组——回想小火山口的形成与随之而来（与灾难相关的）的展现。由于这些形式作为岩浆和地下水混合的结果, 并因此产生爆炸性的蒸气岩浆喷发, 因而作为最难忘的火山灾难现象之一。回想小火山口形成的古老故事为澳大利亚所熟知, 其中过往近乎六万五千年的文化隔离, 解释了这些故事非凡的持久性与反覆的忠诚。本研究同时描绘指涉义大利阿尔巴诺小火山口形成后的发展之故事, 以及来自其他地方且较少被诠释的故事。主题分析显示, 有文字前的人们将其对小火山口形成的观察纳入故事作为鸟儿的尖声鸣叫（释出的气体）以及恶魔的到达（喷发）, 以及诸如天空转红和地表扭曲与崩裂的叙事细节。主题指涉小火山口在喷发后的活动, 包括回忆充满水的火山口, 以及火山口边缘、火山泥流与向下溢流造成的相关破坏。上述描绘的小火山口故事类别的存在, 及其对数千年前的特定事件展现增添细节的潜能, 应鼓励地理学者更为重视此般信息来源, 而非将之视为惯常。*关键词：火山泥流, 在地知识, 小火山口, 小火山口湖, 口述传统, 火山作用。*

Antiguas historias que recuerdan eventos catastróficos fueron elaboradas, a veces cifradas en mitos, y legadas a través de los milenios, en gran medida en contextos orales. El vulcanismo es muy apropiado para tales historias y existen ejemplos de relatos vigentes que recuerdan erupciones ocurridas hace ya miles de años. Este estudio se enfoca en un subconjunto de estas historias —las que recuerdan la formación y manifestaciones subsiguientes (relacionadas con catástrofes) de los volcanes maar. Debido a que estos volcanes se originan como resultado de la mezcla de magma con agua subterránea, que produce erupciones freaticomagmáticas explosivas, aquellos se cuentan entre los fenómenos volcánicos catastróficos memorables. Se conocen historias antiguas referidas a la formación de maars en Australia donde el aislamiento cultural

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por la mayor parte de los pasados 65.000 años explica la extraordinaria longevidad y fidelidad en la replicación de tales historias. También se describen las historias que se refieren a los desarrollos posteriores a la formación maar del Lago Albano en Italia, junto con historias de otras partes interpretadas menos fielmente. El análisis de diseño sugiere que los pueblos preliterarios incorporaron sus observaciones de la formación del maar dentro de historias como el chillido de las aves (escapes de gas) y la aproximación de los demonios (erupciones), lo mismo que detalles de la narrativa como que el cielo se torne rojo y la superficie del suelo se retuerza y rompa. Los motivos referidos a la actividad posterior a la erupción de los maars incluyen los que rememoran cráteres llenos de agua y otras que recuerdan la rotura asociada de los bordes del cráter, lahars e inundaciones cuesta abajo. La existencia de historias del maar como las descritas y su potencial demostrable para agregar detalle y explicación a eventos particulares de hace milenios debe estimular a los geógrafos a tratar tales fuentes de información con más respeto del que se acostumbra.
Palabras clave: conocimiento local, lahar, lago maar, maar, tradiciones orales, vulcanismo.

The recognition by Western science that many ancient stories, often passed on orally for tens of generations to reach us today, might have their roots in fact has been slow in coming (Vitaliano 1973; Barber and Barber 2004). Yet today, there are many examples of such stories and traditions, including those likely to derive from eyewitness accounts of geological (catastrophic) phenomena. These include stories of island (flank) collapse, of earthquakes and associated tsunamis, of meteorite falls, and of volcanism (Piccardi and Masse 2007; Hamacher and Norris 2009; Nunn 2018). In some cases, it has proved possible to reconstruct from these stories details of the nature and impacts of particular geological phenomena that "Western" science might otherwise have been unable to know. Such knowledges come from different sources and have reached us today along different pathways yet complement science, allowing us to optimize our understanding of such phenomena.

Volcanic eruptions and their after-effects, ranging from ash falls to the remobilization of volcanic sediments as lahars, provide memorable material for preliterate peoples to encode in oral traditions, perhaps making the reproducibility of these more attractive by mythologizing the event witnessed, thereby encouraging future generations to pass the stories on. The need for future generations to understand the hazard potential of particular places and landforms was clearly the main purpose of developing such oral traditions. A good example are the place-avoidance stories developed by the Klamath people of Oregon (western United States) that recall the time when the former Mt. Mazama erupted to form modern Crater Lake (Deur 2002), an event that occurred some 7,600 years ago (Egan, Staff, and Blackford 2015).

This article focuses on maar volcanoes and the ways in which their singular mode of formation and their subsequent manifestations became recorded in oral traditions within preliterate societies. The reason for selecting maars is that not only are there such stories from different parts of the world but also the landforms produced by maar eruptions are distinctive and often remain visible in landscapes for millennia, acting as *aides mémoires* for preliterate peoples about the dangers (once) posed by these volcanoes. The next section reviews the geology and distribution of maar volcanoes, especially those that have formed (or been otherwise active) within the past 20,000 years. That is followed by a review of maar stories with case studies from Australia and Italy. The implications of maar stories for illuminating our understanding of maar formation and post-formation threats to nearby human activities are explored in the last section.

Origin and Distribution of Maar Volcanoes

Observations and deductions suggest that maar volcanoes develop when magma moving upward through a lithospheric fissure encounters a body of groundwater just below the ground surface. The resulting phreatomagmatic explosions result in a shower of tephra that settles in a ring around the vent, often lithifying to tuff to form a crater-like landform. These explosions create huge volumes of steam that fracture the host rock, causing abrupt subsidence beneath the crater to form a (inverted cone-shaped) diatreme marking the top of the fissure. These craters may be formed within a few tens of seconds and at most a few tens of minutes (White and Ross 2011).

As the base of the maar crater generally lies below the original ground surface, at least after the initial eruption, groundwater drains into the crater and fills it, percolating down through the fragmented rock material filling the diatreme. Often this groundwater encounters more rising magma, which leads to another phreatic eruption and the deposition of another layer of tephra. Such polygenetic maars are more common than monogenetic ones (Valentine et al. 2017).

Maars are found in (formerly) active volcanic areas on all of Earth's major landmasses (Ollier 1988) and are considered to be the second most common volcano type in subaerial environments (Lorenz 2003; van den Hove et al. 2015). They often occur in clusters, representing points at which magma from the same subsurface magma body reached the surface simultaneously. Owing to their crater-like forms, newly formed maars often fill with water to form lakes. Well-studied examples are the Eifel maars (Germany), perhaps fourteen of which formed during the most recent period of activity which began 50,000 years ago (Schmincke 2007), and the group of about twenty that straddle the Nejapa-Miraflores alignment (Nicaragua) and that formed within the past 25,000 years (Freundt et al. 2010). Diatremes feeding many maars have been mined for precious minerals; most in situ (rather than alluvial) diamonds occur in ancient (pre-Quaternary) kimberlitic diatremes (e.g., Vinokurov et al. 1998; Pouclet et al. 2004).

Maar eruptions are invariably spectacular and dangerous for people in the immediate vicinity. Postformation activity at maars might involve not only eruptive activity but also deformation of maar craters (and associated changes in level of crater lakes), which could also pose long-term hazards to people living nearby. Like other volcanic eruptions, maar volcanoes often produce large volumes of unconsolidated material (typically ash) that is deposited on the (steep) slopes around the maar crater. This material is liable to be mobilized during heavy rainfall in particular, creating debris flows (lahars) that could threaten people in surrounding lowlands. Maar lakes can contain massive volumes of water that could be (partly) released when a section of the maar crater wall collapses. Although these collapses might be earthquake triggered or caused by the subsurface movement of superheated water or magma, the resulting floods invariably affect people living nearby (e.g., Muller and Veyl 1957; Joyce 2005; De Benedetti et al. 2008; Alvarado et al. 2011). Where carbon dioxide is emitted over long periods of time up the diatreme and into the lower parts of a maar lake, these could become highly acidic (CO_2-saturated). Periodic wall collapses of the maar crater at Lake Nyos (Cameroon) released not only water but also large quantities of toxic gas that spread across a wide area downwind and (particularly with CO_2) along valley floors; such an event in August 1986 led to the death by asphyxiation of at least 1,700 people and 3,000 livestock (Kling et al. 1987).

Although the kinds of scientific understanding of maar volcanism discussed thus far are often regarded otherwise (Latour 1999), they are of course cultural products, informed by understandings developed in commonly Greco-Roman contexts. In the next section, comparable explanations for maar volcanism are described, yet these are those that developed in quite distinct situations, geographically or historically removed from modern "global" scientific understanding and informed by others' understandings of the natural world (Agrawal 1995).

Ancient Stories about Maars

Maar eruptive activity within the past 20,000 years must have been witnessed by people in many parts of the world. This study focuses less on written eyewitness accounts than on those rendered orally by preliterate peoples and passed on in this way across many generations to reach us today. The database of such volcano stories is massive and growing, yet most do not lend themselves to systematic analysis either because details are nebulous, associations with place (and time) uncertain, or their authenticity as being based on firsthand observations of volcanism is questionable. To a greater or lesser degree, as explained here, all of the maar stories recounted in this article are considered authentic and therefore suitable for analysis. A second issue is that all of these stories are from secondary sources, not collected directly from informants, and might therefore have been suffused with others' values and beliefs; not least because these stories are readily interpreted factually and because they occur in many extant versions, this issue is considered irrelevant for this study. Finally, because these stories have undoubtedly been passed down (largely orally) for tens, even hundreds, of generations, the possibility that they have been modified remains, although for these stories it is difficult to

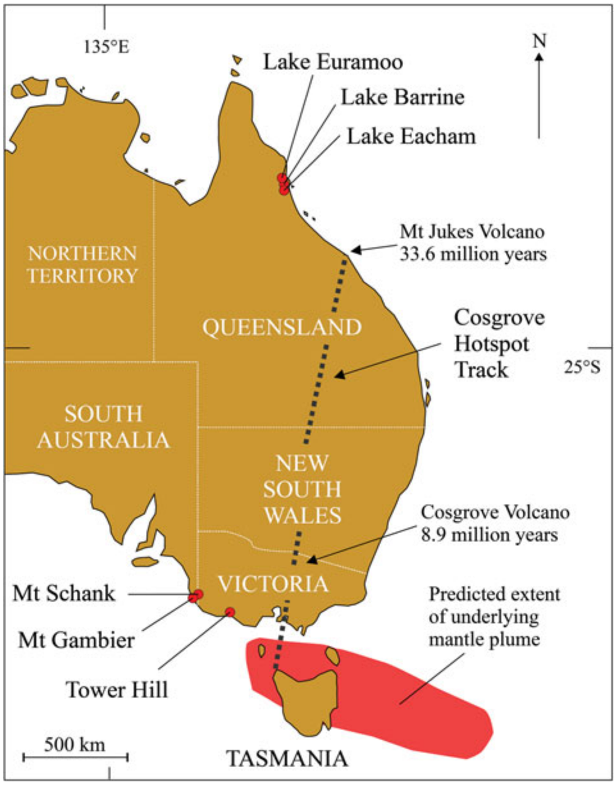

Figure 1. Map of maar volcanoes formed within the last 40,000 years in eastern Australia; also shown is the Cosgrove Hotspot Track that locates the mantle plume beneath Tasmania that might explain the anomalously young volcanism of the Newer Volcanics Province in southern Australia (after Nunn 2018). (Color figure available online.)

imagine how this might have had a profound effect on their contemporary content.

Three case studies are given in the subsections that follow. Two are from Australia, where the dryness of most parts renders maars conspicuous features of the landscape and where, fortuitously, cultural memories are among the world's lengthiest (Nunn 2018). People arrived in Australia around 65,000 years ago (Clarkson et al. 2017) and remained comparatively isolated for most of the subsequent time, encouraging the iterative accumulation of knowledge about various aspects of landscape change (e.g., Hamacher and Norris 2009; Nunn and Reid 2016). A third case study comes from Italy during its Roman history around 2,000 years ago and focuses on oral traditions and beliefs about likely resurgent maar volcanism. Another subsection discusses other possible oral recollections of maar activity and a final subsection interprets these maar stories through motif analysis to try to isolate what aspects of maar behavior were most commonly witnessed by people.

Case Study: Newer Volcanics Province, Southern Australia

Straddling the southern border between the two states of Victoria and South Australia, the Newer Volcanics Province (NVP) consists of 416 separate centers active within the past 4.5 million years, plausibly as a result of magma leakage from the mantle plume to the southeast that was responsible for the formation of the Cosgrove hotspot track (Matchan and Phillips 2011; Boyce 2013; Davies and Rawlinson 2014). Perhaps eight of these centers have been active within the past 20,000 years, two of these being monogenetic maars—Blue Lake, part of the Mt. Gambier maar complex (Gouramanis, Wilkins, and De Deckker 2010), and Mt. Schank (Figure 1), which is considered to be the youngest of all Australian volcanoes (Johnson 2007).

One story is of the giant Craitbul and his family, who are said to have occupied several dry maar craters (including Mt. Gambier and Mt. Schank) in the area and were accustomed to cooking their food within the warm ground within these craters (J. Smith 1880). The Craitbul family lived in fear of the demon Tennateona—a likely recollection of eruption—but were invariably forewarned of his approach by the shrill cry of the *bullin* (bird?)—a possible recollection of a distinctive audible precursor of eruption, like the hiss of escaping gas or even initial subsurface contact between magma and groundwater. The story recalls that once the Craitbul family reached Mt. Gambier, they felt safe from Tennateona but eventually moved because their "ovens" kept on filling with water, a likely memory of the periodic filling of maars here (Nunn 2018). Mt. Gambier was last active about 5,000 years ago (Blackburn, Allison, and Leaney 1982) and Mt. Schank about 4,930 years ago (B. W. Smith and Prescott 1987), requiring that Aboriginal Australians not only closely observed many aspects of maar activity but also found it sufficiently memorable to encode in oral traditions and pass these on coherently for perhaps more than 200 generations.

Among the largest maars in the world, Tower Hill was once thought to have erupted last about 4,300 years ago (Bindon and Raynal 1998), yet more recent work has shown that it formed about 35,000 years ago and has been inactive since (Sherwood, Oyston, and Kershaw 2004). The point of mentioning this is that there are no Aboriginal stories about the formation of the Tower Hill maar, a fact that supports the likelihood of these stories elsewhere in the NVP being genuinely related to observations of volcanism (euhemeristic myths or stories) rather than having been arbitrarily invented or applied to any likely looking landform (etiological myths or stories).

Case Study: Atherton Tablelands, Northern Australia

There is uncertainty about the cause and even the chronology of anomalously young volcanism in northern Queensland (Cohen et al. 2017; see Figure 1), which centers on the maar (and other) crater lakes of the Atherton Tableland. There are eight maar lakes in the area, at least one of which—Lake Eacham—has an Indigenous story recalling its formation. It talks about two newly initiated young men who protocol required were confined to camp while their elders went hunting. Needing to defecate, one of the young men left camp in breach of protocol. The other followed and by accident they threw a spear at a flame tree that embodied the Rainbow Serpent, the most powerful and vengeful of supernatural beings in Australian Aboriginal lore.

> The camping-place began to change, the earth under the camp roaring like thunder. The wind started to blow down, as if a cyclone were coming. The camping-place began to twist and crack. While this was happening there was in the sky a red cloud, of a hue never seen before. The people tried to run from side to side but were swallowed by a crack which opened in the ground. (Dixon 1972, 29)

The "noise," the unusual "wind," the "twisting" and "cracking" of the ground are all consistent with the formation of a maar, as is the "redness" of the sky from an eruption plume; such effects are all reconcilable with those reported in more recent eyewitness accounts of maar formation (e.g., Muller and Veyl 1957; Self, Kienle, and Huot 1980).

This Aboriginal story, repeated in different places with slightly differing details, is always applied to Lake Eacham but occasionally also extended to the neighboring maars of Lake Barrine and Lake Euramoo, which are older. It is estimated by sediment radiocarbon analysis that Lake Eacham formed a minimum of 9,130 years ago, which is therefore a minimum age for the observations on which this story is based, whereas Barrine formed at least 17,300 years ago and Euramoo around 23,000 years ago (Whitehead et al. 2007). Another indicator of the antiquity of the myth describing Lake Eacham's formation is the description of the flora at the time of the eruption. A Dyirbal (Aboriginal) story describes the type of vegetation at the time and location as "not jungle—just open scrub" (Dixon 1991, 41). A minimum age for the presence of rainforest has been determined by the analysis of pollen grains trapped in sediments at nearby Lake Euramoo at 7,600 years ago (Kershaw 1970). This supports the suggestion that this story is at least this old. The oldest maar crater on the Atherton Tablelands is Lynch's Crater, which formed at least 230,000 years ago (Kershaw, Bretherton, and van der Kaars 2007); reassuringly, there are no Aboriginal stories about its formation.

Case Study: Lake Albano Maar, Central Italy

A short distance from the southeast part of the city of Rome, the Lake Albano maar is the youngest eruptive center within the Colli Albani Volcano (Funiciello, Giordano, and De Rita 2003; De Benedetti et al. 2008). The time when it formed is uncertain; estimates range from around 36,000 years ago to a mere 8,000 years ago (Andretta and Voltaggio 1988; Freda et al. 2006). Either way, it seems highly unlikely, given the minimum age and the high-frequency cultural admixing in this region, that any stories recalling the origin of this maar are extant. What is of interest in this case study are memories of its post-formation changes, especially the lake-overturn (rollover) events that have probably occurred on more than one occasion.

The Albano maar lake is unusually deep—167.5 m. Today, its surface lies about 70 m below the lowest part of the crater rim (at 293 m above sea level), which in turn lies some 85 m above the fertile Ciampino Plain, posing a historical and contemporary threat to its inhabitants (Figure 2A). In fact, there is abundant evidence from the distribution of lahar (debris flow) deposits across the Ciampino Plain that it was affected on at least one occasion by a series of lahars. Lahars formed the *Conglomerato del Tavolato* around 5,800 years ago (De Benedetti et al. 2008), the emplacement of which must have had major effects on the inhabitants of the Ciampino Plain and nearby lowlands (Gioia et al. 2010). This event is inferred to have been caused by maar-lake

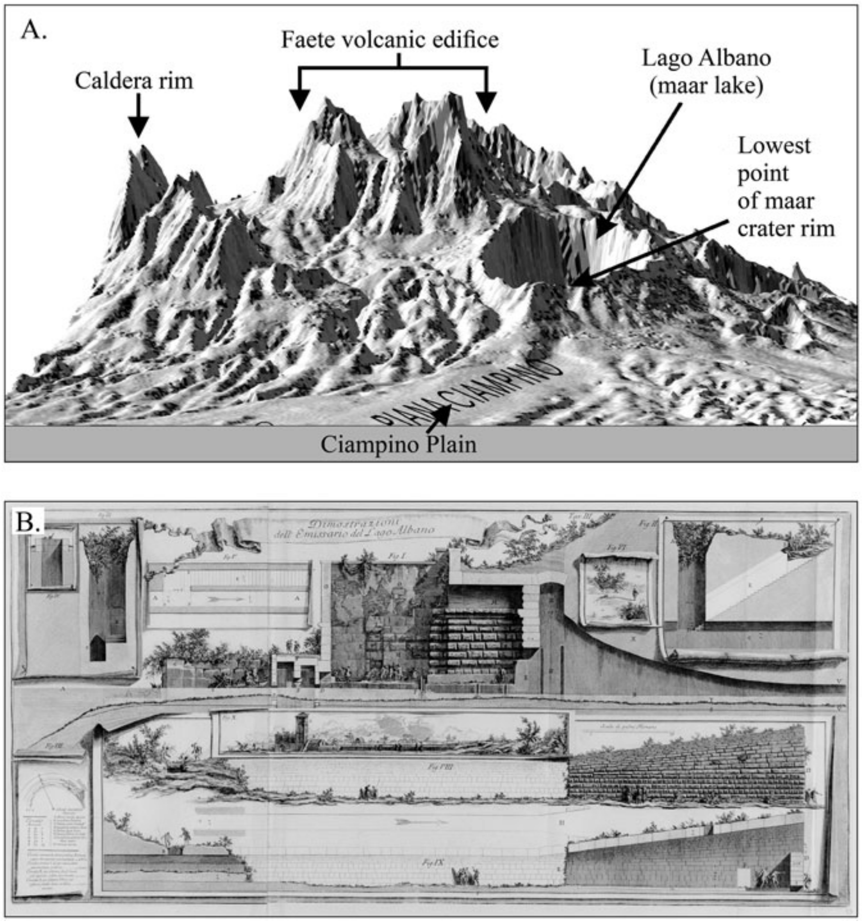

Figure 2. The nature of the Lake Albano (Lago Albano) maar in central Italy and its human modification. (A) Three-dimensional model showing the volcanic edifice of which the Albano maar is part, as well as the Ciampino Plain over which it lies (after Funiciello, Giordano, and De Rita 2003; original courtesy of Guido Giordano). (B) Etching (1762) by Giovanni Battista Piranesi of the outlet (*emissario*) created by "the ancients" through the crater wall of the Lake Albano maar (courtesy of Ghent University Library).

overspill, something likely to have been a result of both prolonged rainfall and—most important—an accompanying reduction, perhaps sudden, in the capacity of the maar crater associated with crustal deformation attributable to the upwelling of "gas and hydrothermal fluids" (Funiciello, Giordano, and De Rita 2003, 57).

The latter process is also the most probable cause of the more recent spillover of the Albano maar lake, which occurred in 398 BC (about 2,400 years ago). Noted by later chroniclers[1] as having happened during a prolonged dry period, the lake level is said to have risen calmly up to the crater rim 70 m higher than today, a typical indicator of crustal (ground-surface) swelling known as bradyseism that often occurs in such seismically and volcanically active areas (Lima et al. 2009). The weight of the water pressing against the crater rim caused its partial collapse and associated catastrophic flooding across the Ciampino Plain below.

Some of the effects of this event were recorded. For example, Dionysius of Halicarnassus stated that

> A certain lake, distant not less than one hundred and twenty stades from Rome in the Alban mountains, as they are called, beside which in ancient times the mother-city of the Romans was situated, at a time when neither rains nor snowstorms had occurred nor any other cause perceptible to human beings, received such an increase to its waters that it inundated a large part of the region lying round the mountains, destroyed many farm houses, and finally carved out the gap between the mountains and poured a mighty river down over the plains lying below. (Cary 1950: XII, 10)

Similarly, Plutarch stated that

> But the Alban lake, which had its source and outlet within itself, and was girt about with fertile mountains,

> for no reason, except it be that heaven willed it, was observed to increase and swell until it reached the skirts of the mountains and gradually touched their highest ridges. All this rise was without surge or billow. At first it was a prodigy for neighbouring shepherds and herdsmen. But when the volume and weight of water broke away the barrier which, like an isthmus, had kept the lake from the country lying below it, and a huge torrent poured down through the fields and vineyards and made its way to the sea, then not only were the Romans themselves dismayed, but all the inhabitants of Italy thought it a sign of no small evil to come. (Perrin 1914: Themistocles and Camillus, 3)

Archaeological confirmation of the catastrophic flooding of the Ciampino Plain comes from excavations at the Villaggio delle Macine site, which was buried and abandoned during this event, forcing its inhabitants to move to the Albano crater rim (516–556 m above sea level) where they founded the town of Albalonga (Chiarucci 1996).

Alarmed by the catastrophic nature of the 398 BC event so close to Rome itself, the Roman authorities sent emissaries to the Oracle at Delphi to understand what was assumed to be the divine cause of the catastrophe—and what the best response would be. At the time, Romans were besieging the rich Etruscan city of Veii (16 km northwest of Rome), which was considered to be under the protection of Neptune (god of water and earthquakes), so when the Oracle explained the Albano crater collapse and flood to be the expression of Neptune's fury, it was believable to the Romans. The oracles at both Delphi and Cumae made explicit a particular course of action.

> The gods and genii to whom had been allotted the oversight of the city of Veii guaranteed to maintain for them unshaken the good fortune of their city as handed down from their ancestors for only so long a time as the springs [waters] of the Alban lake should continue to overflow and run down to the sea; but that when these should forsake their natural bend and, quitting their ancient courses, should turn aside to others, so as to mingle no longer with the sea, then too their city would be overthrown. (Cary 1950: XII, 12)

Thus it was that the Romans then started to construct a tunnel through the Albano crater wall along which the lake water could drain to mingle no more with the sea[2]; Veii was finally taken by Rome in 396 BC, and the tunnel was completed in 394 BC. Although details of precisely how this tunnel was constructed 70 m below the crater rim, given that the lake level was probably still higher than this, remain incompletely known, it was built (Figure 2B) and has successfully kept the lake level here low ever since (Funiciello, Giordano, and De Rita 2003; De Benedetti et al. 2008).

Like Lake Nyos (discussed earlier), the main hazard from Lake Albano today is toxic gas release. Historical records[3] suggest that gas clouds emanated from the crater in 639 BC and 585–586 BC and spread across the neighboring landscape. These events might have occurred when the lake level was comparatively high, so the chances of similar events occurring today, given that the lake level is kept artificially low, are less (De Benedetti et al. 2008). It is clear that the ancient Romans at the time of the Albano tunnel construction were aware of the presence of pressurized fluids in the ground below the Albano maar (De Benedetti et al. 2008) and knew from earlier history that associated gas emissions (especially carbon dioxide and hydrogen sulphide) posed a significant hazard (Todesco and Giordano 2010).

Other Maar Stories

Less well documented than the three preceding case studies, there are fragments of oral traditions and stories about maar origins and activities from other parts of the world that might plausibly represent eyewitness observations.

Part of the 1,000-km-long Trans-Mexican Neovolcanic Belt, the Oriental-Serdán Basin contains numerous maars that were known to the original inhabitants of the region as *axalapaxco*, meaning "crater with a lake" in Nahuatl (Alvarez and Yutsis 2017). An unpublished story about the Aljojuca maar (Anonymous 2018a) recalls how in the midst of a prolonged drought, a cow returned from grazing with wet hooves. Together with the girl who owned the cow, the local people located a "puddle" where the maar now lies. Transforming herself into a mermaid, the girl entered the puddle and it slowly grew into the maar lake that exists today. This story might recollect a time when Aljojuca (re-) filled, possibly shortly after it formed during the early Holocene, plausibly 7,000 to 8,000 years ago (De Leon Barragán and Carrasco-Núñez 2014).

Table 1. Maar stories and their likely interpretations

Volcano	Eruption motifs reported in stories	Corresponding volcanic phenomena	Posteruption motifs reported in stories	Corresponding volcanic phenomena
Mt. Schank (NVP, Australia)	Alarming cries of *bullin*	Steam generation and escape (eruption precursor)		
	Approach of Tennateona (greatly feared)	Maar eruption (initial?)		
Mt. Gambier (NVP, Australia)			Ability to cook food in earth	Ground warm because of magma close to surface
			Earth ovens flooded	Maar lake filling with water
Lake Eacham (N. Australia)	Roar like thunder	Sounds of subsurface magma movement		
	Wind like cyclone	Escaping gas and steam		
	Ground twists and cracks	Maar volcano forms		
	Red clouds	Eruption cloud		
Lake Albano (Italy)			Unnatural lake water rise and flood/lahar	Bradyseisms reduce lake capacity
Lake Pupuke (New Zealand)			Rangitoto created when Pupuke formed	Eruption of Pupuke maar involving rocks being thrown seawards (toward Rangitoto)
			Hollow appears (grows) in land and becomes filled with water	Maar crater deepening from bradyseisms
Aljojuca (Mexico)			Puddle forms during drought	Maar lake forms (immediately posteruption)
			Puddle grows into lake	Maar lake deepens

Notes: NVP = Newer Volcanic Province.

A line of active volcanoes runs along the axis of the North Island of New Zealand and includes the maar of Lake Pupuke, now surrounded by Auckland city suburbs. A Maori (Indigenous) story recalls how a couple (or family of giants) living there had cause to insult Mahuika, the goddess of fire, who retaliated by destroying their home, removing the land and mountain where they lived (to create Lake Pupuke), and dumping this offshore (to create Rangitoto Island; Nichol 1992). Although the formation of Rangitoto is dated to 1312 AD (638 cal BP), the maar appears much older (Horrocks et al. 2005). This implies that the contemporaneity implied in the myth is wrong and that the "formation" of the Pupuke maar recalled by the myth is more likely a period of reactivation, perhaps marked by eruption and subsidence.

The Changbai Volcanic Field in eastern China is one of the most active intraplate strato-volcanic areas in the world and includes the Tianchi Plinian volcano. Yuanchi (Circular Pool) is a small but mythologically significant maar lake 33 km east of Tianchi (Sun et al. 2018). The volcanic area around the Tianchi volcano hosts many myths and legends drawn from Chinese and Korean oral traditions that include euhemeristic stories relating to recent volcanic events. One myth states that the ancestors of the Manchu were born beside the "pool" of a goddess mother who accidently ate a plant seed, which "was once held in the beak of a red bird" (Wei, Taniguchi, and Liu 2002, 196).

In the Eifel Mountains of Germany, where many maars exist, it is the late Pleistocene ages of most of these combined with the fact that the surrounding lands were not occupied continuously by the same groups of people throughout the Holocene that likely explain an apparent absence of extant stories here recalling maar activity (Herbig and Sirocko 2013).

The 2,300-year-old Ubehebe maar in Death Valley, California, was created over a short period of time and would have been manifested as spectacular phreatomagmatic eruptions from fourteen different points (Champion et al. 2018). It is highly likely that this activity would have been noticed by local people, although no stories have been identified other than the name of *Tem-pin-tta- Wo'sah* (Coyote's Basket) that describes the form of Ubehebe maar, not its creation; this is the name given to it by the Timbisha Shoshone people (Anonymous 2018b).

Motif Analysis of Maar Stories

Various motifs (elements) of the maar stories recounted here are identified and interpreted in Table 1. It appears likely that all or most of these recall particular manifestations of maar formation and postformation development that science has been able to explain only more recently. This underlines the importance of treating such stories as potential sources of information about past volcanism, something that has implications for the understanding of contemporary hazards in maar settings.

Discussion

Although it is clear that the maar stories recounted here are good examples of valuable Indigenous or local knowledge that merits incorporation into strategies for disaster risk reduction (Cronin and Cashman 2008; Mercer et al. 2010; Lauer 2012), the issues of how long these stories have endured and how this happened are also worth discussing. Figure 3A shows the likely (minimum) ages for the maar stories discussed earlier. These ages represent the least time that these stories must have been kept alive by people living close to (or otherwise acquainted with) a particular maar.

It can be seen from Figure 3A that maar stories have endured for various lengths of time within the past ten millennia. Although there are admittedly some uncertainties surrounding what certain stories apparently recall and how long these have endured, the information shown—especially the best documented examples from Australia and Italy—does demonstrate how long such stories may endure through (largely) oral means. Figure 3B helps put the maar stories within the broader context of "volcano stories" that recall other (nonmaar) expressions of volcanism. Among the best documented of these those from Hawai'i Island, Kadavu Island

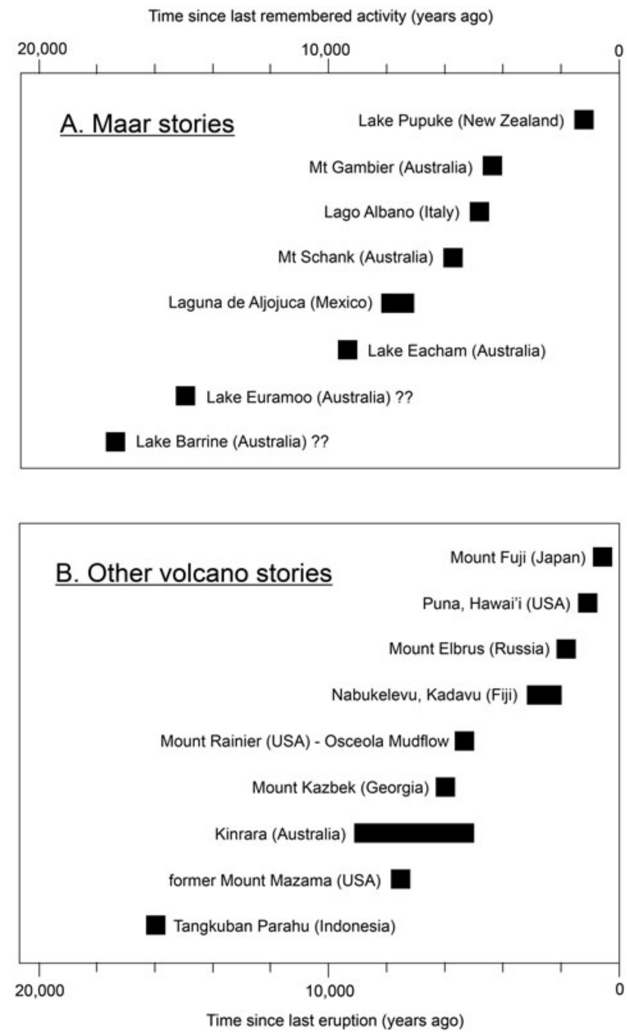

Figure 3. Ages of (oral) stories about volcanic and related phenomena. (A) Minimum estimated ages for stories about the volcanic (associated) activity at maar volcanoes. (B) Minimum estimated ages for stories about nonmaar volcanic activity (after Nunn 2018). Sources of age data as follows: Mount Fuji (Yamamoto et al. 2005), Puna (Masse, Carter, and Somers 1991), Elbrus (Lebedev and Vashakidze 2014), Nabukelevu (Cronin, Ferland, and Terry 2004), Rainier (Vallance and Scott 1997), Kazbek (Lebedev and Vashakidze 2014), Kinrara (Cohen et al. 2017), Mazama (Egan, Staff, and Blackford 2015), and Tangkuban Parahu (Ry et al. 2015).

(Fiji), Kinrara (Australia), and Mount Mazama (United States), each discussed separately next.

The emphasis in Indigenous Hawaiian cultures on the oral recollection of chiefly genealogies has allowed the indirect age determination of many eruptions within the last millennium (Swanson 2008). The Puna event shown in Figure 3B is recalled by a story dating from the reign of King Keali'iokaloa, about 1525 to 1600 AD, that explains how someone who should have known better failed to show respect to the volcano goddess, Pele. She responded by chasing him downslope at high speed and into the sea—a likely recollection of a lava eruption from Kilauea (Masse, Carter, and Somers 1991).

The volcano named Nabukelevu (the "large yam mound") at the western end of Kadavu Island in southern Fiji was once thought to have become extinct about 50,000 years ago. Yet a persistent story told by the people of nearby Ono Island recalls how one day their view of the sunset became obscured by the growth of Nabukelevu. This story has been interpreted as recalling the formative eruption of Nabukelevu (Nunn 1999), which subsequent research suggests occurred 780 to 2,250 years ago (Cronin, Ferland, and Terry 2004).

The Kinrara volcano, located some 150 km southwest of the maar lakes in northern Queensland (shown in Figure 1), was shown to have erupted around 7,000 years ago, an event recorded in Australian Aboriginal stories belonging to the Gugu Badhun peoples (Cohen et al. 2017). Among these stories are ones that recall a time when the watercourses caught fire—a likely recollection of times when lava flowed down them—and when a witch doctor dug a pit, stirring up the earth to create a cloud in which people could not see and many were asphyxiated.

Mount Mazama terminally erupted about 7,600 years ago, creating a caldera that became Crater Lake in Oregon (Egan, Staff, and Blackford 2015). Several Klamath stories recall this event, typically focusing on its causes (human–god interactions), explaining its manifestations (god–god conflict) and its aftermath, which saw an evil deity buried within the caldera by a benign one. The presence of the former explained why the Klamath avoided the area, something that drew the attention of some of the earliest literate people there (Deur 2002; Barber and Barber 2004).

Given the great, perhaps unanticipated, antiquity of such volcano stories, it is then worth considering whether there might be other similar stories in existence. The answer is almost certainly "yes"; there are two issues to consider. The first is that such stories have generally been dismissed by most scientists in the past as being of no or little intrinsic value to the scientific understanding of the world. This is explainable by the unfamiliar forms in which such knowledge is presented to scientists, something that diminishes its potential for many of them, as well as the fact that many such stories are known only orally; the "arrogance of literacy" has encouraged the dismissal of such knowledge (Nunn 2018, 23–24). The second issue is that such stories are currently disappearing from collective human memory faster than perhaps ever before; it seems inevitable that unless such stories are preserved for posterity soon, the knowledge they contain is likely to be forever lost. There would seem to be value in identifying and evaluating the potential of such stories to inform science, especially in those parts of the world where these are still largely rendered orally.

Conclusion

This article has highlighted the nature of ancient stories about volcanic maars to illuminate the understanding of how they formed and how they manifested themselves subsequently. This study shows that such maar stories can remain current for perhaps as long as nine or ten millennia, certainly for four to five millennia. This suggests that human societies would have created stories and myths about such memorable phenomena not simply to warn future generations about the hazardous nature of particular places but also to contextualize identity: where a people had come from, what experiences they had had, and how they had survived particular hazards.

There are likely to be many similar stories about maars and other manifestations of volcanism from within the past 10,000 years hidden within many of the oral "libraries" of the world's longest-enduring cultures. Similarly, when many of these libraries were written down for the first time, some of these stories were likely to have become incorporated in written history and traditions, many assumed to be "legends" invented as part of the development of cultural identity; in some instances, this assumption is demonstrably wrong (Kelly 2015; Nunn 2018). The potential for such stories to inform scientific understanding of geological history is clear (Piccardi and Masse 2007).

Recognition that non-Western (or traditional) knowledges have something to contribute to the scientific understanding of the world has been growing over the past two decades (Nunn 2014). Especially in poorer contexts, where people threatened by impending catastrophe or disaster are reluctant to embrace adaptive solutions informed by unfamiliar (Western) science, the use of local knowledge is increasingly being used (Mercer et al. 2007; Cronin and Cashman 2008). Similarly, the failure of external interventions for climate change adaptation over several decades has been attributed to their secular global (acultural) nature in local contexts that are culturally and spiritually informed (Nunn and Kumar 2018). The need to privilege local knowledge for effective and sustained outcomes in such situations is becoming manifest (Cruikshank 2007; Yunkaporta and McGinty 2009; Lebel 2013; Rudiak-Gould 2014; Santha, Gahana, and Aswin 2014).

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Notes

1. These people, who mostly lived between 100 BC and AD 100, include Dionysius of Halicarnassus (Cary 1950: XII, 10-11), Plutarch (Perrin 1914: Themistocles and Camillus, 3), Livy (Foster 1924: V, 15), Valerius Maximus (Bailey 2000: I, VI, 3), Cicero (Falconer 1923: De Divinatione, I, 100), Julius Obsequens (Schlesinger 1959: XVII). Some of these people, at least Dionysius and Livy, who spent most of their lives in Rome, probably visited the area around the lake and collected local traditions that inform their accounts.
2. The fact that this tunnel probably enlarged or rejuvenated an Etruscan tunnel dating from the seventh century BC (Coarelli 1991) hints that there might have been earlier collapses of the Albano crater wall and an associated catastrophic flood that local authorities sought to prevent from happening again.
3. Principally the 4th-century AD account by Julius Obsequens (Schlesinger 1959).

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